Digital Receiver Test Results

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Table of Contents

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1. Summary Results

The following is a brief description of the Sigmet 12 bit and 14 bit digital receiver testing and results. Emphasis was placed on measurement of end to end radar system phase noise and receiver dynamic range. Phase noise was measured in both the time and frequency domain as rms phase jitter and noise below the carrier. Dynamic range is divided into the truly linear, i.e., from noise level to maximum signal with no limiting and from noise level to 1 dB compression point.

It was found that radar system phase noise with both the legacy and digital receivers are essentially the same. Background phase noise is about 63 dB below the carrier (-63 dBc) with the 12 bit digital receiver and about -64dBc with the legacy and 14 bit digital receivers. Also, there is no indication of quadrature signal distortion due to the digital synchronous detection process.

The legacy receiver linear and 1 dB compression dynamic ranges are 87 dB and 92 dB. The 12 bit digital receiver linear and 1 dB compression dynamic ranges are 81 dB and 85 dB. The 14 bit digital receiver linear and 1 dB compression dynamic ranges are 88 dB and 93 dB. The 12 bit digital receiver is marginal for the WSR-88D application. The 14 bit receiver performance matches the legacy performances.

It is recommended that a 14 bit digital receiver (or larger) be incorporated into the Open RDA before deployment. The digital receiver has very important maintainability/reliability advantages over the legacy receiver. Nine LRU’s may be removed from the receiver channel as well as all of the critical legacy receiver channel adjustments.

2. Analog to Digital Converter Basic Tests

Normally twelve engineering parameters are used to describe the detected performance of an analog to a digital converter. However, for purposes of high-level performance specifications, only four parameters are needed. These parameters and associated values are given in Table 1 for the WSR-88D converter (HAS-1201-SMB), the Sigmet 12 bit converter (AD 9042) and the Sigmet 14 bit converter (AD6644). All ADC’s are products of Analog Devices.

Figure 1 is an example of AD 9042 testing for missing codes and differential linearity. The input signal substantially exceeds the ADC range and produces a pseudo uniform distribution of signal amplitude (with exceptions of extreme values). Under these conditions, the fractional occurrence in a given category (ADC number) is proportional to the category width and this width minus the reciprocal of the total ADC span, 4096 in this case, is the differential linearity. An example of 1201 differential linearity factory testing is shown in Figure 2. An example of 1201 integral linearity testing is shown in Figure 3. Integral linearity is also a measure of category width variation but since it is measured from the best fit transfer, its trends indicate systematic distortion in the ADC transfer function. No missing codes or deviations from specified linearity were noted for either ADC.

An example of ADC noise and harmonic level testing is shown in Figure 4. The signal to noise ratio is measured by summing the signal power and noise power, including signal harmonics in this case, by FFT coefficient and taking the ratio. The noise level in practical ADC's (particularly large high speed devices) is higher than the ideal ADC due to non-linearities in the conversion and the additive thermal noise. The quantization noise power in the ideal is given by the variance introduced by quantifying an analog range of values into an ADC category. The best estimate of the analog value is the midpoint of category and the uncertainty is one half the category width. The variance or noise introduced by this process is the variance associated with a uniform probability density across the category, i.e.,

$$\sigma^2 = \frac{(LSB)^2}{12}$$

where

$$\sigma^2 = noise\ power$$
$$LSB = category\ width$$

For the ideal ADC, quantization, noise is 10.8 dB below the power associated with the LSB squared.

ADC noise level is usually measured by injecting a signal with peak value slightly less than ADC full scale. For the example shown in Figure 4 and Table 1, the signal peak value is placed at 1 dB below full scale which places the rms value at 4 dB below full scale. A signal to noise ratio of 67 dB (12 bit ADC's) places the noise at 71 dB below full scale or 5 dB below the LSB^2. This measurement is in reasonable agreement with the expected noise for a thermal noise of 0.33 LSB rms (AD9042 values at 25°C) corresponding to a thermal noise level of 9.6 dB below LSB^2 and a differential linearity of 0.5 LSB corresponding to a noise about 9.5 dB below LSB^2 resulting in a composite noise level about 6.5 dB below LSB^2. A measured SNR of 73.5 dB (14 bit ADC) places the noise at 77.5 dB below full scale or 0.5 dB above the LSB^2. ADC performance is summarized in Table 1.

Table 1
ADC Performance Summary

Device	Analog Devices Model	Differential Linearity (Typ)	Missing Codes	Signal to Noise Ratio[1], dB	Integral Linearity	Thermal Noise
Legacy - 12 bit	1201	± 0.6 LSB	None	64 min, 67 typ	± 0.75 LSB	
Sigmet - 12 bit	9042	± 0.4 LSB	None	64 min, 67 typ	± 0.75 LSB	.33 LSB rms
Sigmet - 14 bit	6644	± 0.25 LSB	None	72 min, 73.5 typ	± 0.5 LSB	

Differential Linearity - The deviation of any code from an ideal 1 LSB step.
Integral Linearity - The deviation of the transfer function from a “best straight line” determined by a least square fit.

(1) SNR with analog input peak power at 1 dB below full scale.

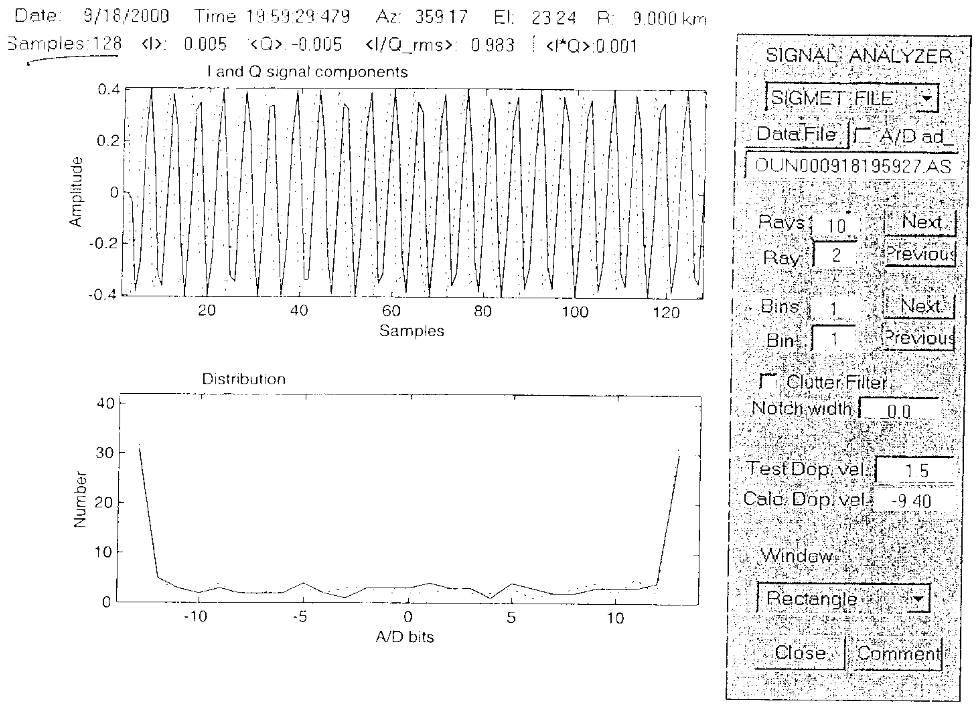


Figure 1. Example of AD 9042 Testing for missing codes and differential linearity. Upper panel is plots of the complex video and lower panel is amplitude distribution of the quadrature signals, ADC is over driven resulting in the peak occurrences of the ADC range extremes. No missing codes noted.

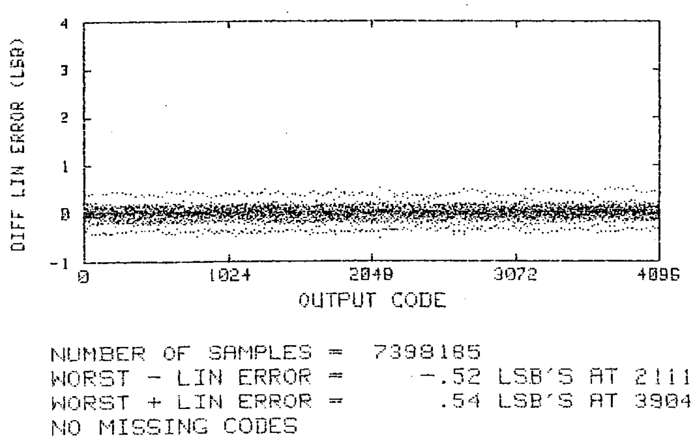


Figure 2 Example of factory measurement of differential linearity of 1201 ADC.

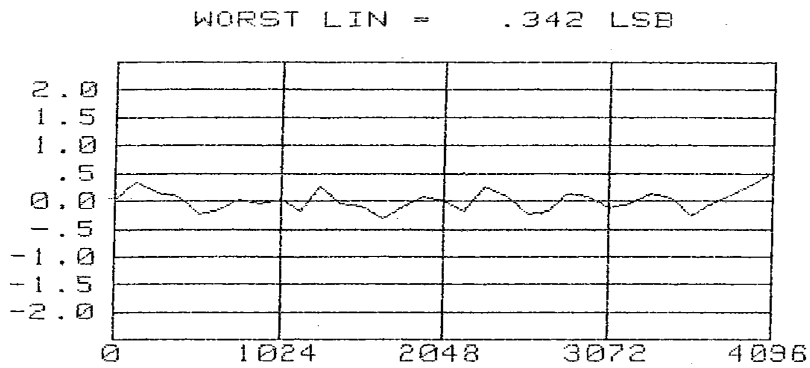


Figure 3. Example of factory measurement of integral linearity of 1201 ADC.

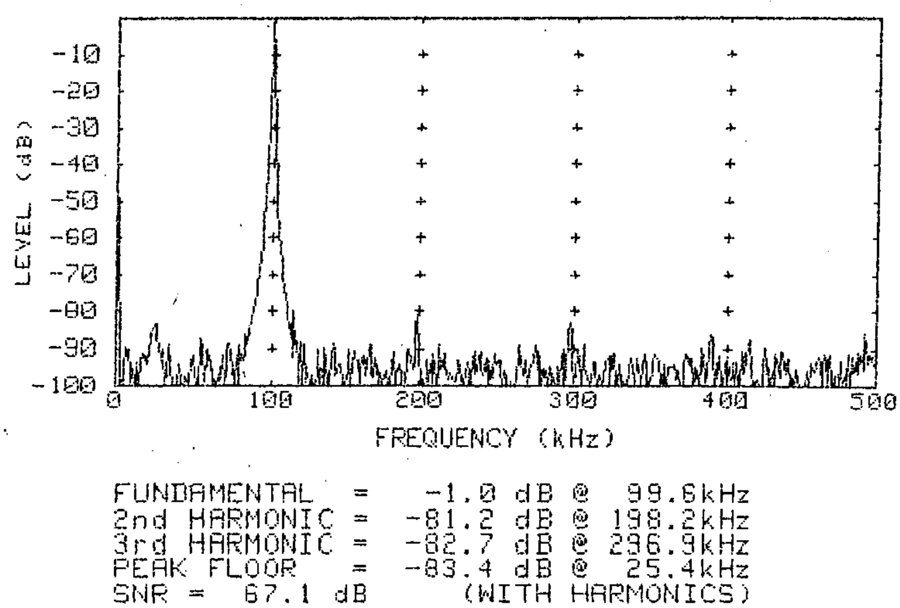


Figure 4. Example of factory measurement of ADC 1201 quantization noise level by use of a 512 point DFT. Signal peak is set 1 dB below full scale.

3. Receiver Phase Noise

In radar systems such as the WSR-88D, background noise can be divided into the three classes, i.e., thermal noise, phase noise, and quantization noise. Thermal noise is the noise due to component temperature and the noise coupled through the antenna and is essentially constant at about -110 dBm to -112 dBm referenced to receiver input. Phase noise is due to small perturbations of the signal and is at a fixed level below the signal. Quantization noise, like thermal noise, is constant but at a level relative to the ADC scale. As seen from the previous section, the 12 bit ADC quantization noise is expected to be about 5 dB below the power associated with LSB^2 and the 14 bit ADC quantization noise is expected to be about equal to power associated with LSB^2.

The sum of these three noise contributions results in a signal to noise behavior whereby, as signal level increases, the signal to noise increases linearly so long as the thermal noise is larger than the sum of phase and quantization noise. However, when the input signal level reaches a level where the phase noise is larger than the thermal and quantization noise, the signal to noise ratio does not increase with input signal but remains at signal to phase noise level. Alternately, if the quantization noise becomes larger than the thermal and phase noise and, if this occurs in the region where the quantization noise is at a constant level below the signal (such as the active AGC region for the legacy receiver), then the signal to noise does not increase with input signal but remains at the signal to quantization noise level. Either condition results in a “noise floor” which limits the system maximum performance.

There are two basic methods of specifying and measuring the phase noise. One is a direct measurement in the frequency domain such as illustrated in Figure 4. The other method is a time domain measurement of the rms phase jitter. With either method, the source of the noise, i.e., thermal, quantization or phase, cannot be determined directly from the measurement. Phase noise power and rms phase jitter are related through the following:

Given that the peak phase fluctuations are much less than one radian, i.e., higher order modulation components are insignificant compared to the fundamental modulating frequency, then from small angle modulation theory

$$\frac{(\phi peak)^2}{2} = (\phi rms)^2 = S\phi(f)$$

where

$$\phi peak = peak\ phase\ deviation, radians$$

$$\phi rms = rms\ phase\ jitter, radians$$

$$S\phi = single\ sideband\ phase\ noise\ relative\ to\ carrier, dBc$$

As with the spectral density measurement, the rms phase jitter is due to system noise, i.e., we cannot directly distinguish between thermal noise, quantization noise, or phase noise. (A limitation of the rms phase jitter method is lack of information on frequency distribution of the jitter.) In the testing, three phase jitter calculations are made; (1) Sigmet rms phase is calculated in the Sigmet A Scope Utility, (2) ang RMS is calculated from the complex video periodiagram used by the Utility (but not necessarily the same samples) and (3) ang power which is calculated from the same samples as ang RMS as a power weighted angle.

Sigmet angle and angle RMS are calculated as follows:

$$\phi n = \frac{180}{\pi} arc\tan \frac{In}{Qn}$$

where

In, Qn are the inphase and quadrature video.

$$\Delta\phi n = (\phi_{n+1} - \phi_n)$$

$$\Delta\phi rms = \left[\frac{1}{N-1}\sum_{1}^{N-1}\Delta\phi_n^2\right]^{1/2}$$

where

N = number of samples

The parameter ang Power is calculated by

$$\Delta\phi_n = \frac{180}{\pi}\arctan\frac{\mathrm{Im}(Zn\,Z^{\neq}n+1)}{\mathrm{Re}(Zn\,Z^{\neq}n+1)}$$

where

Z = I + jQ and Z$^{\neq}$ *= complex conjugate of Z*

$$angPower = \left[\frac{1}{N-1}\sum_{1}^{N-1}\Delta\phi_n^2\right]^{1/2}$$

The primary difference between ang RMS and ang Power is that the quadrature signals used to determine the angles for ang Power are power weighted since the product *Zn Zn***+1* delivers a vector with length equal to the product of the lengths of *Zn* and *Zn+1*. (The *ZnZ***n+1* product is used in the WSR-88D signal analysis schemes.)

Examples of phase noise measurement by both spectral density and rms phase jitter is shown in Figure 5 (a) through 5 (i). These are a series of measurements on the delayed klystron signal and provide a measure of radar system phase noise with the Sigmet 12 bit receiver. Input signal level varies from a thermal SNR of 24 dB to 89 dB and corresponds to attenuator settings of 60 dB to 0 dB. Results of this test run are tabulated in Table 2.

As seen from Figure 6, the linear and power weighed phase jitters are essentially the same implying that Signet Utility provides a quantitative estimate of phase noise as reflected in the WSR-88D calculations.

Phase noise level relative to carrier as calculated from ang RMS (time domain) and by Noise_ Skirt level (frequency domain) is shown in Figure 7. Noise_Skirt is the regions from +12.5 ms^{-1} to 25 ms^{-1} and from -12.5 ms^{-1} to   -25 ms^{-1} and is the best estimate of noise level in the presence of the strong test signal. As seen, the two estimates are generally within 2 dB of each other and either method can be used to measure phase noise.

A comparison of Δ ϕ *rms* by the Sigmet Utility and Δ ϕ *rms* by ang RMS is given in Figure 8. Agreement is reasonable considering that these are statistically independent estimates of the same process.

Radar system phase noise with the WSR-88D receiver (12 bit ADC) and with the Sigmet receiver

(12 bit ADC) is shown in Figure 9a. The legacy system phase noise was measured in the frequency domain using FFTRD, a toolbox utility in the WSR-88D. The test signal is the delayed klystron output injected into the receiver front end which provides a complete radar system test. As seen, the system rms phase jitter and background noise decreases with thermal signal to noise ratio down to a thermal SNR of about 63 dB at which point the phase jitter and background noise becomes constant at about .04 degrees rms and -63 dBc. This noise level is, of course, the system noise floor imposed by the combination of radar phase noise and quantization noise.

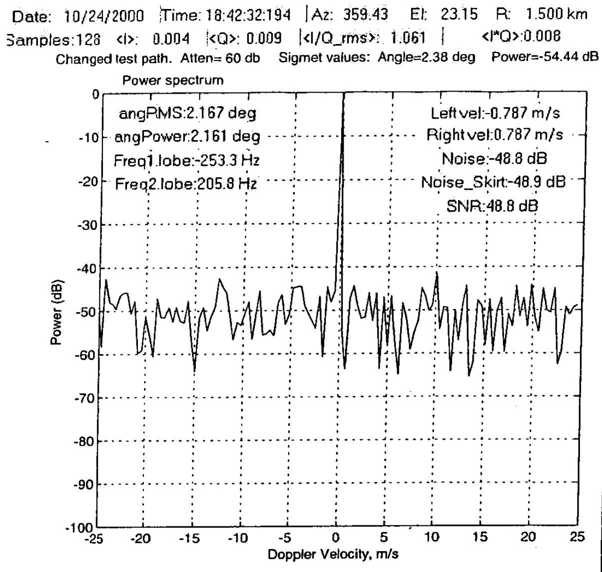
Radar system phase noise with the Sigmet 14 bit receiver is shown in Figure 9b. The radar system thermal noise and digital receiver noise relative level setup was the same for both 12 bit and 14 bit receivers. Radar thermal noise was set to raise composite noise by 2 dB. The 12 bit digital receiver noise is about 69 dB below full scale and the 14 bit receiver noise is about 76 dB below full scale. The fact that the noise floor is about the same for both receivers, i.e., about -64 dBc at therm SNR's of 70 dB to 80 dB, implies that this is the radar system noise with little contribution from ADC quantization and internal noise.

An important conclusion can be drawn from the data in Figure 9a and 9b. In terms of the radar system, the noise performance of the Sigmet and the legacy receivers are the same within a dB or so. This implies that for phase noise levels greater than about -65 dBc, the synthesizer techniques used by the digital receiver, which require precise phase locking and timing, work as well as the classic analog techniques used in the legacy receiver.

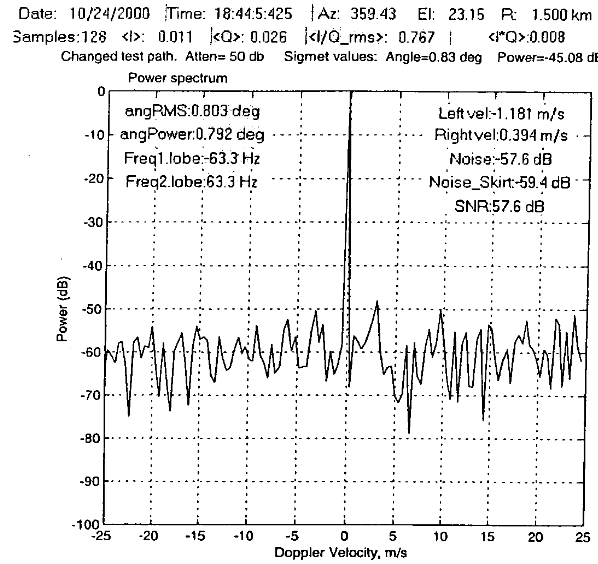
Table 2
Phase Noise Measurement Summary - Sigmet 12 bit Receiver
Modified Test Path Δ pwr = 15.6 dB

Atten dB	Pwr dB	Thermal SNR, dB	$\Delta\phi$s deg	$\Delta\phi$v deg	Noise_S dBc	dBc S(f)	dBc ϕ
0	+1.68	89	0.42 deg	0.232 deg	-69.8 dBc	48.7	35.2
5	-0.34	84	0.05	0.042	-85.3	64.25	61.2
10	-5.05	79	0.035	0.046	-83.9	62.8	64.3
15	-10.07	74	0.04	00.53	-83.0	61.9	63.1
20	-14.88	69	0.04	0.053	-92.2	61.1	63.1
30	-24.82	59	0.08	0.091	-77.8	56.7	57.1
40	-34.94	49	0.26	0.236	-67.7	46.6	49.9
50	-45.08	39	0.83	0.803	-59.4	38.3	36.8
60	-54.44	29	2.38	2.167	-48.9	27.8	27.6

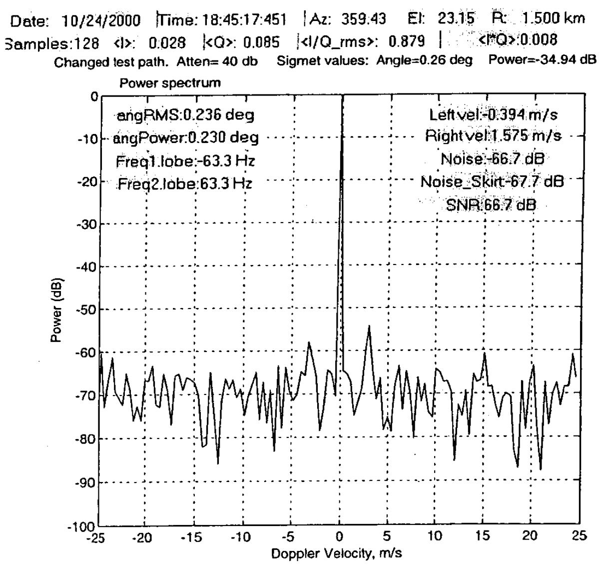
$\Delta\phi$s = rms phase jitter as calculated by Sigmet Utility
$\Delta\phi$v = rms phase jitter as calculated offline from I,Q samples
Noise_S = noise level in frequency domain with 128 samples
dBc, S(f) = phase noise level below carrier as estimated in the frequency domain
dBc, Q = phase noise level below carrier as estimated from rms phase jitter (time domain)



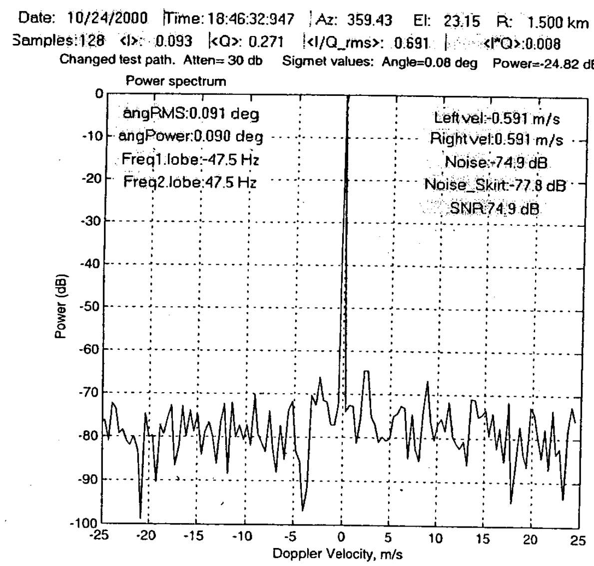
(a) 29 dB.



(b) 39 dB.



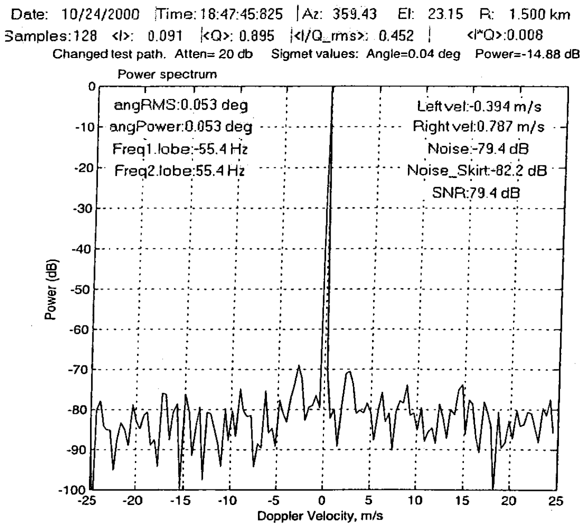
(c)49 dB.



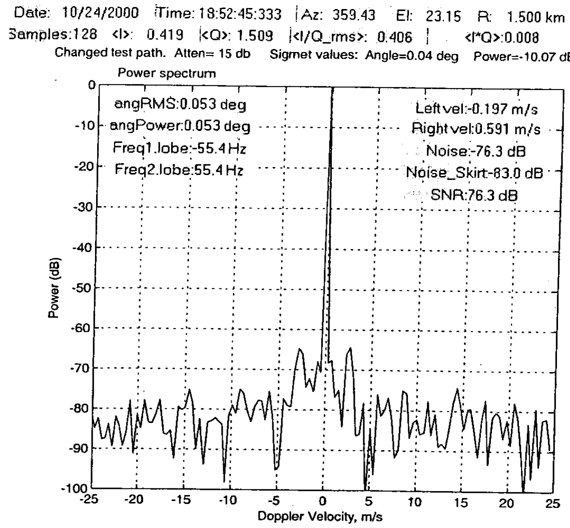
(d) 59 dB.

Figure 5 Phase jitter and composite noise level measurement at given thermal signal to noise ratios of (a) 29 dB, (b) 39 dB, (c)49 dB, and (d) 59 dB. Sigmet 12 bit ADC.

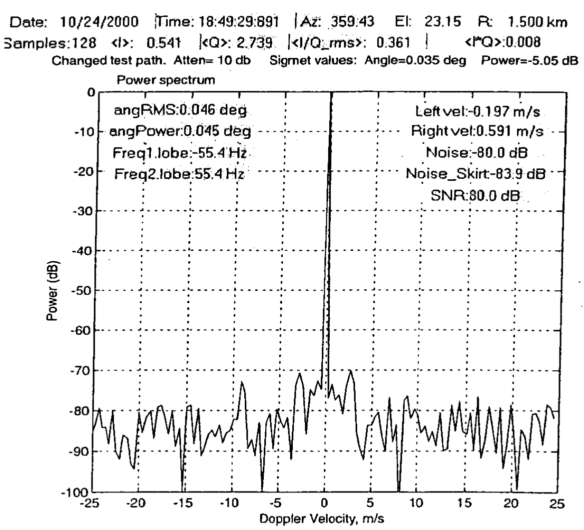
Figure 5 (conti) Phase jitter and composite noise level measurement at given thermal signal



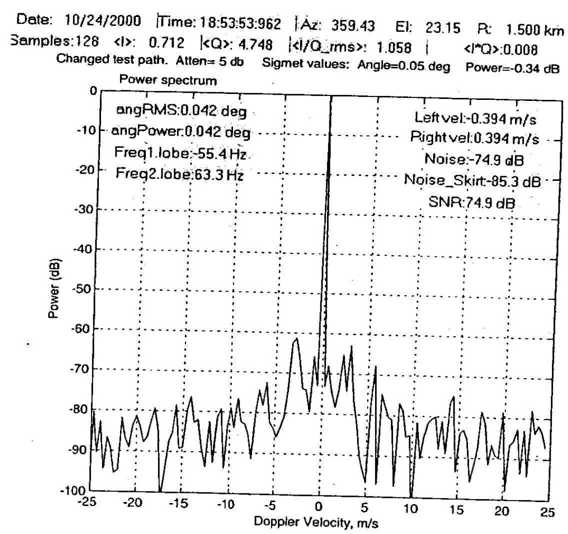
(a) 69 dB.



(b) 74 dB.

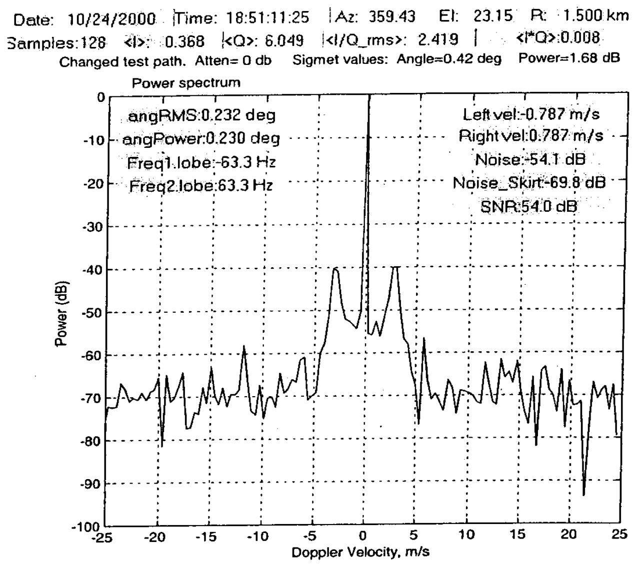


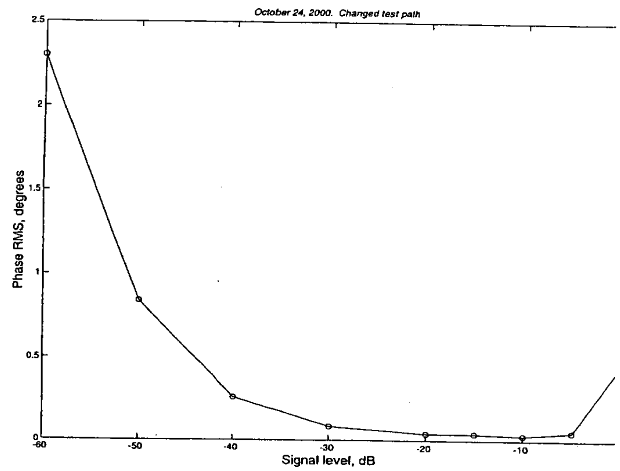
(c) 79 dB.



(d) 84 dB.

to noise ratios of (a) 69 dB, (b) 74 dB, (c) 79 dB, and (d) 84 dB.



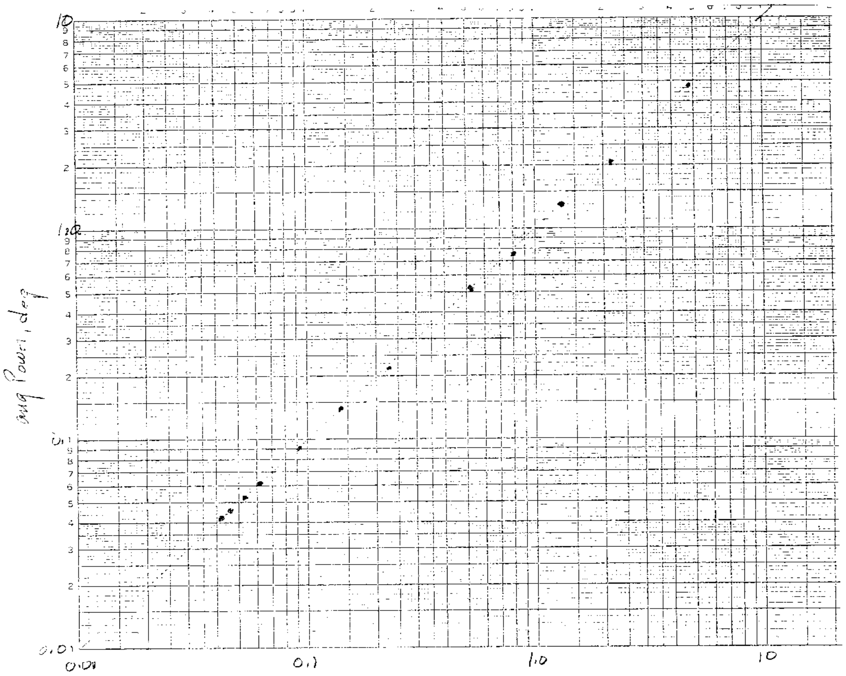


89 dB.

Figure 5 (conti)

(a) Phase jitter and composite noise level measurement of thermal signal to noise ratio of 89 dB. Receiver is saturated as seen from $\Delta\phi$, Noise Skirt, and signal distortion.

(b) $\Delta\phi$ rms versus attenuation setting, Thermal SNR = 89 dB - Attenuation Setting. Sigmet 12 bit Receiver



ang RMS, deg

Figure 6 Power weighted phase jitter, ang Power, versus linear phase jitter, ang RMS.

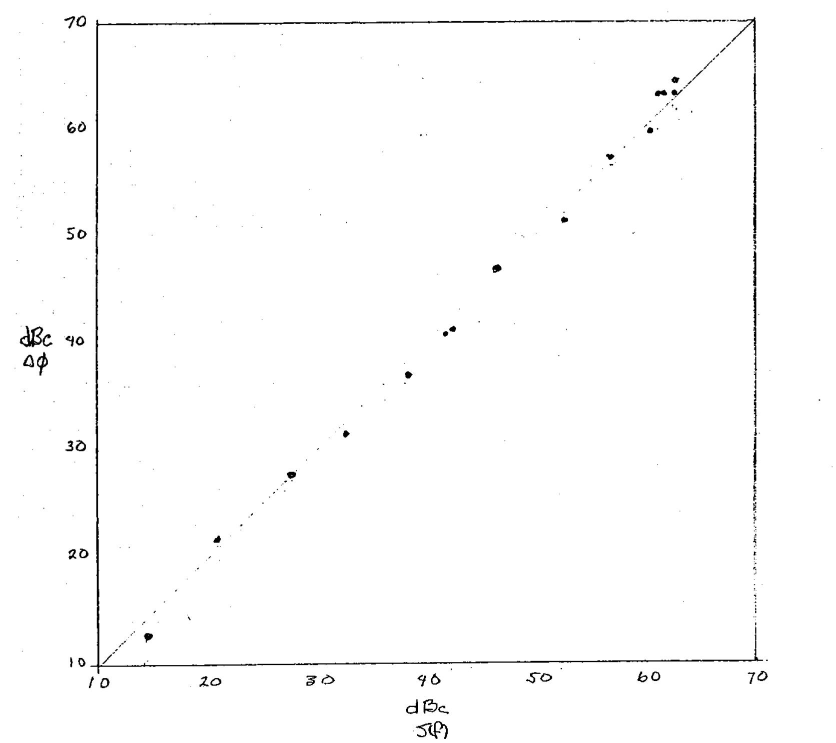


Figure 7 Phase noise as estimated of Δϕ, ang RMS, versus phase noise as measured the FFT, Noise Skirt. Note that the FFT is more sensitive to noise introduced by receiver saturation.

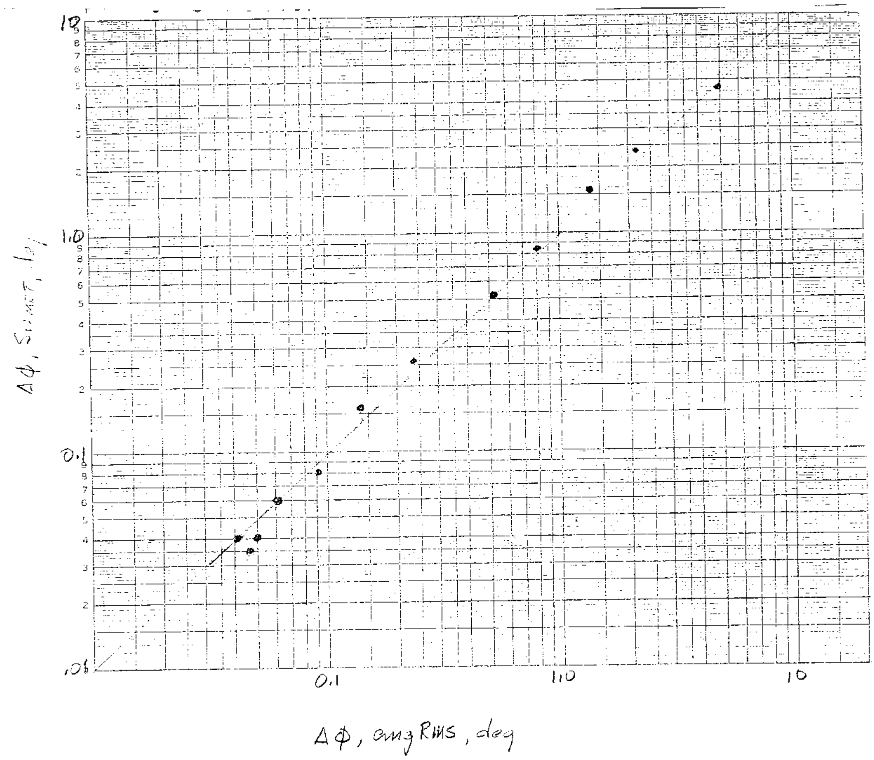


Figure 8 Phase jitter by Sigmet Utility versus phase jitter by off line calculation, ang RMS.

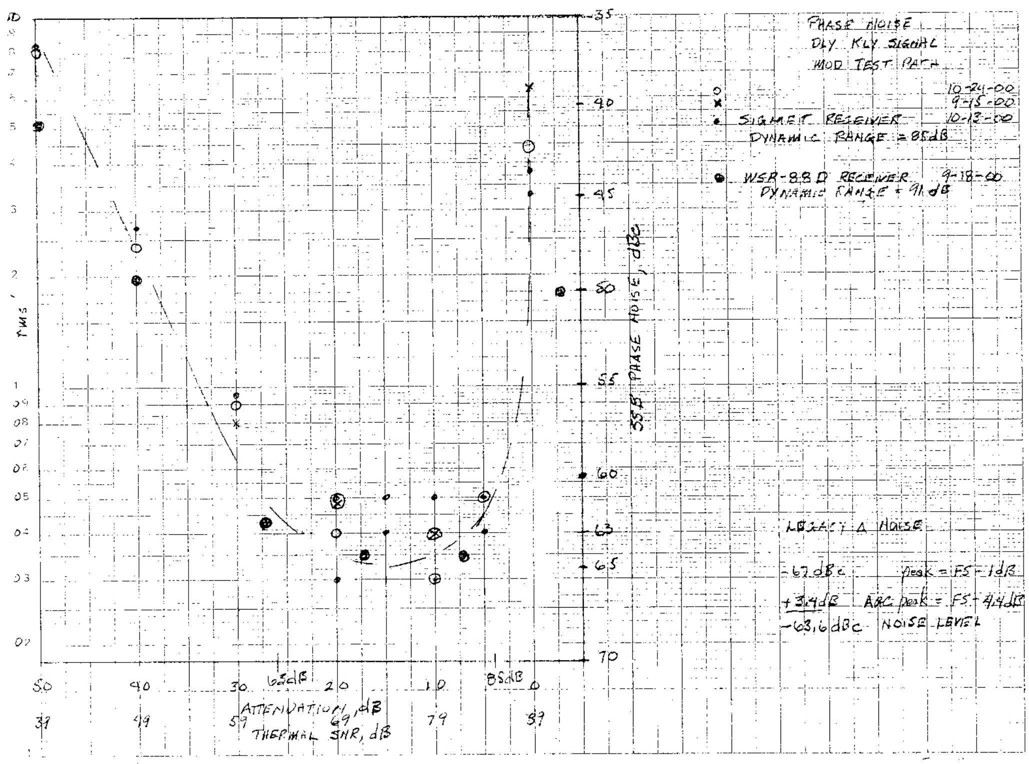


Figure 9a Radar system phase noise with the 12 bit Sigmet and legacy receivers. System noise is essentially the same with either receiver. The noise floor is about -63 dBc for the 12 bit Sigmet and about -64 dBc for the legacy.

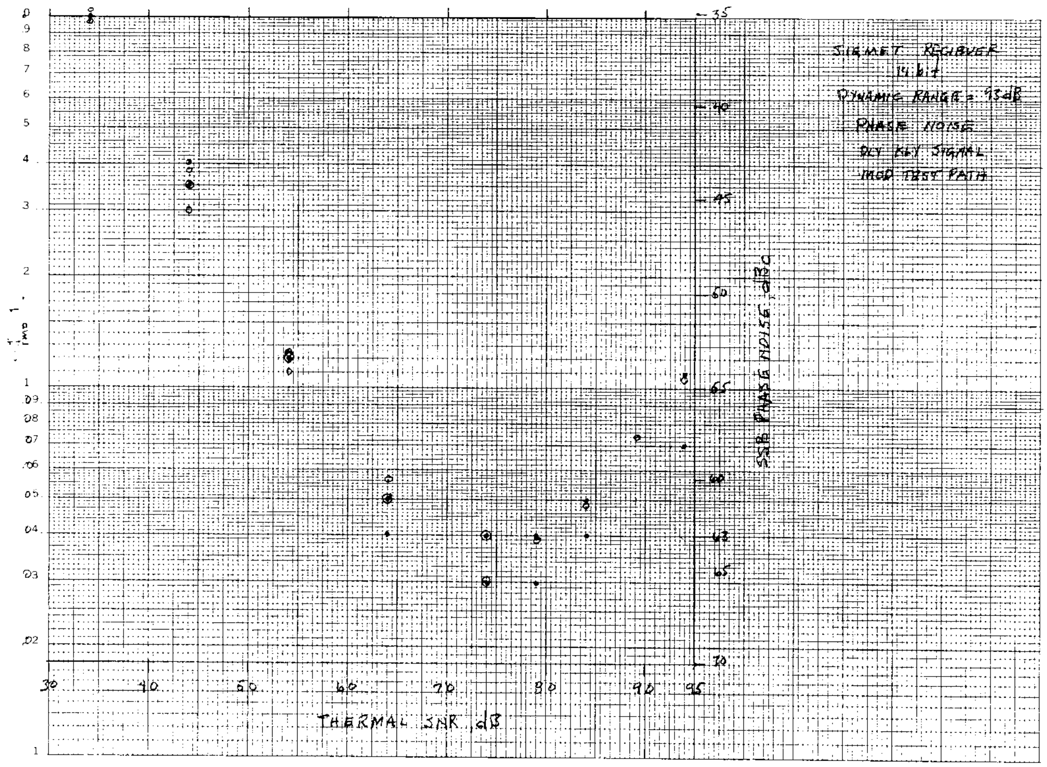


Figure 9b Radar system phase noise with the 14 bit Sigmet receiver. Noise floor is about -64 dBc; the same as the legacy receiver.

4. Receiver Dynamic Range

An important parameter in the WSR-88D system is receiver dynamic range. Dynamic range by convention is taken as the ratio of the 1 dB signal compression point level to the receiver noise level. This range must be capable of handling the variations in meteorological signal power as well as the large powers associated with ground clutter return.

Typically, the dynamic range of the legacy receiver is 91 to 92 dB and is accomplished with a 12 bit ADC by use of an instantaneous automatic gain control (AGC) in the receiver IF chain. During the phase noise test run of September 18, 2000 shown in Figure 9, the dynamic range was 91 dB and for the dynamic range test example shown in Figure 10, the dynamic range was 92 dB. Dynamic range to the 1 dB compressions is not the truly linear range, i.e., the range for no signal limiting. From Figure 10, it is seen that the linear range is about 87 dB.

Both the Legacy and the Sigmet 12 bit receivers use 12 bit ADC's (2'S Complement) having an inherent dynamic range of 66 dB from LSB to full scale. However, in practice the full dynamic range cannot be realized due to noise quantization and in some cases, signal clipping prevention (headroom) requirements.

In the legacy receiver with the normal receiver transfer setup, the noise rms is about 1.7 bits or 4.6 dB above LSB and signals above the AGC threshold are "leveled" to 60 % of full scale or 4.4 dB below full scale providing an ADC dynamic range of 57 dB. The AGC expands the dynamic range over that of the ADC by 58 dB to a total dynamic range of 115 dB. However, the receiver prior to the AGC begins limiting at about 93 dB to 95 dB above noise.

The Sigmet receiver does not use an automatic gain control. The dynamic range is extended beyond that usually associated with a 12 bit ADC by placing the noise at less than 1 LSB at the low end and operating with some clipping of the IF carrier at the high end of input power range. The overall digital receiver dynamic range is expanded by performing the matched filtering and associated noise reduction after digitization and synchronous detection.

The digital receiver dynamic range can be estimated from the following parameters and considerations as outlined by Zrnic in the RADCAL paper "Digital Receiver vs. Signal Processing." The Sigmet 12 bit ADC analog quiescent noise is about 0.6 LSB rms with an input bandwidth of 100 MHz (Analog Devices Specifications). The WSR-88D IF bandwidth is 25 MHz. In the Sigmet receiver the radar system noise is set to increase composite noise by 2 dB, i.e., 2 dB above the value with no signal applied. Since power is conserved in the ADC sampling process and considering the two noise bandwidths, this places the composite system noise at 0.8 LSB rms or 1.9 dB below the LSB. The matched filter bandwidth in the Sigmet receiver is 0.6 MHz (same as the legacy receiver.) However, matched filtering is after the digital synchronous detection rather than before detection and analog to digital conversion as in the legacy. With radar IF bandwidth of 25 MHz the matched filter provides a 16.2 dB increase in dynamic range by noise reduction. Thus, from noise level to ADC full scale, the dynamic range is 67.9 dB due to ADC size and setup plus 16.2 dB due to noise reduction for a total of 84.1 dB. Full scale for signal peak (no limiting) places the signal rms at 0.707 full scale or 3 dB below full scale and thus the truly linear dynamic range is 80.8 dB. Dynamic range from noise level to the 1 dB compression point corresponds to a 1 dB deviation from a linear transfer or an amplitude compression factor of 1.12. From the first harmonic level of the clipped signal, this is estimated to occur at an input amplitude of 1.3 full scale or 2.28 dB above full scale for an estimated dynamic range of 86 dB. This estimate compares reasonably well with the measured dynamic range of 84.4shown in Figure 11a.

The dynamic range of the 14 bit unit is estimated in a similar fashion. Quiescent noise is about 1 LSB with input bandwidth of 250 MHz. A 2 dB increase places the composite noise at 1.26 LSB which results in a dynamic range due to ADC size and setup of 76 dB. Matched filtering and 1 dB compression factors are the same at 16.2 dB and 2.28 dB for a truly linear dynamic range of 88.2 dB and a total dynamic range of 94.5 dB. This estimate compares reasonably well with the measured dynamic range of 93.2 dB shown in Figure 11b.

Some input signal parameters such as mean frequency can be recovered in the presence IF carrier limiting, i.e., above the 1 dB compression point, by allowing estimate variance to increase up to a factor of two. However, in WSR-88D applications, the spectral distortion and spectrum width increase as seen in Figure 5 and the phase jitter and noise increase as seen in Figures 9a and 9b, will limit the utility of this region.

Although its noise characteristics are comparable to the legacy, the 12 bit digital receiver cannot achieve the legacy receiver dynamic range of 92 dB with linear range of 87 dB. However, the 14 bit digital receiver meets or exceeds the legacy performance in both noise properties and dynamic range.

C H A N G A I N (D B) V S T E S T A T T E N (D B)

RECEIVER DYNAMIC RANGE MEASUREMENT

TEST ATTEN DB	CHANNEL PWR DB	OUTPUT S/N DB	GAIN DB
103.00	-48.48	6.72	54.52
102.00	-48.11	7.09	53.89
101.00	-47.74	7.46	53.26
100.00	-48.13	7.06	51.87
99.00	-47.69	7.51	51.31
98.00	-47.14	8.06	50.86
97.00	-47.07	8.12	49.93
96.00	-46.82	8.37	49.18
95.00	-46.45	8.74	48.55
94.00	-46.10	9.10	47.90
93.00	-45.47	9.73	47.53
92.00	-45.15	10.04	46.85
91.00	-44.60	10.60	46.40
90.00	-43.97	11.22	46.03
89.00	-43.35	11.85	45.65
88.00	-43.16	12.04	44.84
87.00	-42.33	12.87	44.67
86.00	-41.64	13.56	44.36
85.00	-40.84	14.35	44.16
84.00	-40.42	14.77	43.58
83.00	-39.60	15.59	43.60
82.00	-38.69	16.51	43.31
81.00	-37.33	17.37	43.17
80.00	-37.06	18.14	42.94
79.00	-36.04	19.16	42.96
78.00	-35.19	20.01	42.81
77.00	-34.16	21.03	42.84
76.00	-33.55	21.64	42.45
75.00	-32.49	22.70	42.51
74.00	-31.58	23.62	42.42
73.00	-30.56	24.64	42.44
72.00	-29.70	25.50	42.30
71.00	-28.63	26.56	42.37
70.00	-27.75	27.45	42.25
69.00	-26.69	28.51	42.31
68.00	-25.85	29.34	42.15
67.00	-24.83	30.37	42.17
66.00	-23.89	31.31	42.11
65.00	-22.82	32.38	42.18
64.00	-21.78	33.42	42.22
63.00	-20.67	34.53	42.33
62.00	-19.81	35.38	42.19
61.00	-18.68	36.52	42.32
60.00	-17.93	37.27	42.07
59.00	-16.80	38.39	42.20
58.00	-15.89	39.31	42.11
57.00	-14.77	40.42	42.23
56.00	-13.89	41.31	42.11
55.00	-12.76	42.43	42.24
54.00	-11.88	43.32	42.12
53.00	-10.74	44.45	42.26
52.00	-9.98	45.21	42.02
51.00	-8.38	46.31	42.12
50.00	-7.93	47.27	42.07
49.00	-6.83	48.36	42.17
48.00	-5.73	49.47	42.27
47.00	-4.63	50.57	42.37
46.00	-3.77	51.43	42.23
45.00	-2.96	52.24	42.04
44.00	-2.20	52.99	41.80
43.00	-0.96	54.23	42.04
42.00	0.17	55.37	42.17
41.00	1.30	56.49	42.30
40.00	2.19	57.39	42.19
39.00	3.22	58.42	42.22
38.00	4.09	59.29	42.09
37.00	5.43	60.62	42.43
36.00	6.31	61.50	42.31
35.00	7.42	62.61	42.42
34.00	8.31	63.51	42.31
33.00	9.20	64.39	42.20
32.00	10.16	65.36	42.16
31.00	11.32	66.51	42.32
30.00	12.26	67.45	42.26
29.00	13.34	68.54	42.34
28.00	14.18	69.38	42.18
27.00	15.22	70.41	42.22
26.00	16.34	71.53	42.36
25.00	17.42	72.61	42.42
24.00	18.42	73.61	42.42
23.00	19.48	74.68	42.48
22.00	20.37	75.57	42.37
21.00	21.21	76.40	42.21
20.00	22.08	77.27	42.08
19.00	23.19	78.39	42.19
18.00	24.21	79.40	42.21
17.00	25.24	80.44	42.24
16.00	26.10	81.29	42.10
15.00	27.10	82.30	42.10
14.00	27.97	83.16	41.97
13.00	29.24	84.43	42.24
12.00	30.15	85.34	42.15
11.00	31.17	86.37	42.17
10.00	32.07	87.26	42.07
9.00	32.63	87.83	41.63
8.00	33.59	88.79	41.59
7.00	34.71	89.91	41.71
6.00	35.48	90.68	41.48
5.00	36.40	91.59	41.40
4.00	37.64	92.24	41.04
3.00	37.69	92.89	40.69
2.00	38.14	93.34	40.14
1.00	38.14	93.33	39.14
0.00	38.53	93.73	38.53

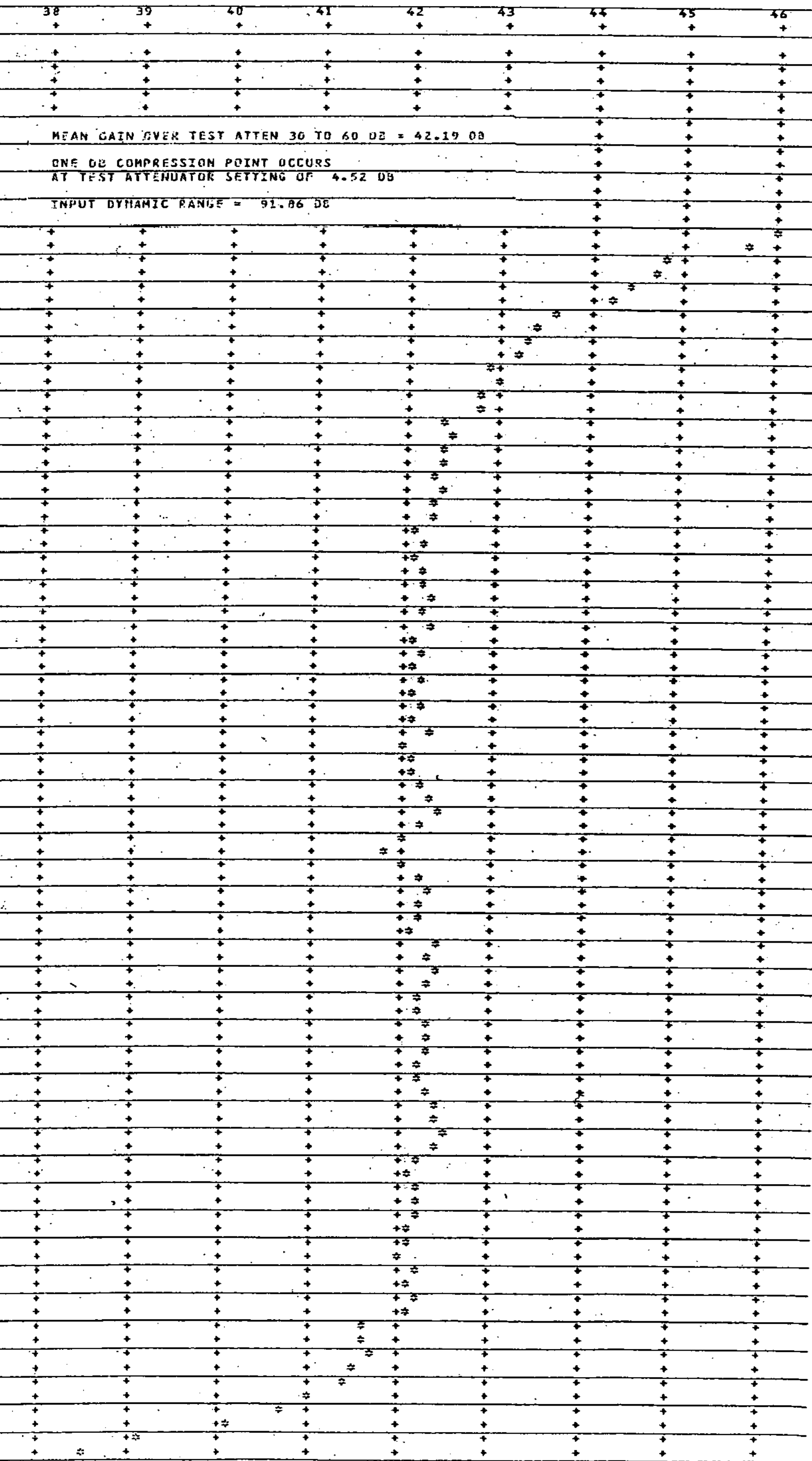


Figure 10 Legacy receiver dynamic range test. The 1 dB compression point is measured as the 1 dB deviation from the average gain in linear transfer region. Dynamic range from noise level to 1 dB compression level is 91.86 dB.

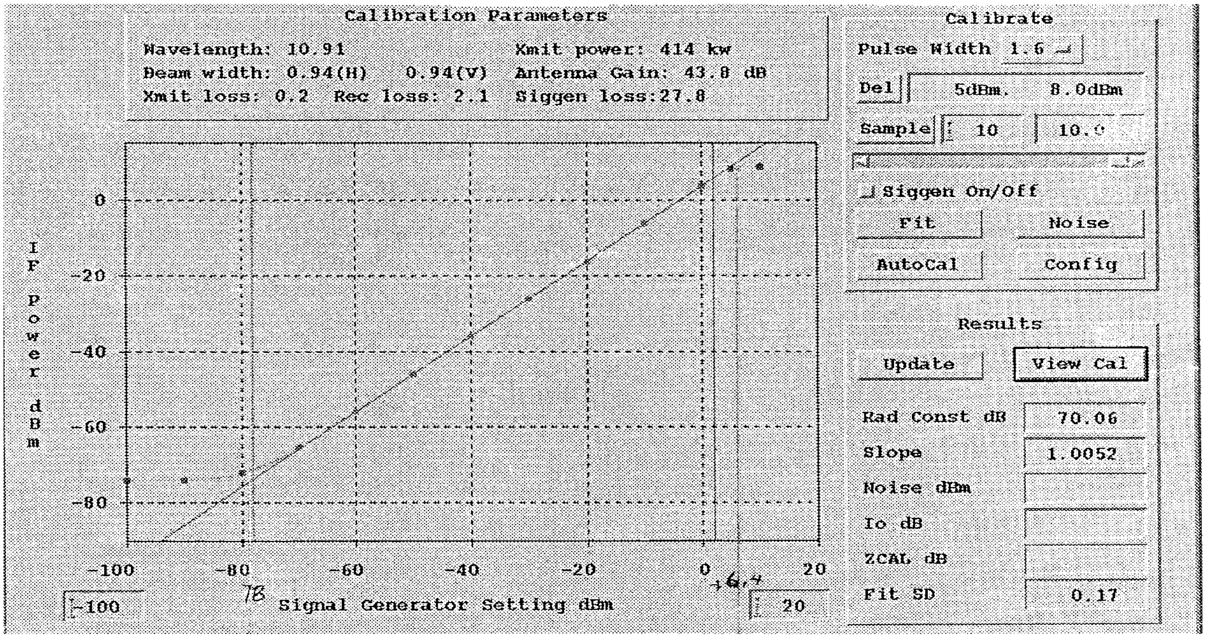


Figure 11a Sigmet 12 bit receiver dynamic range test. The 1 dB compression point is the 1 dB deviation from the linear transfer. Dynamic range from noise level to 1 dB compression point is 84.4 dB.

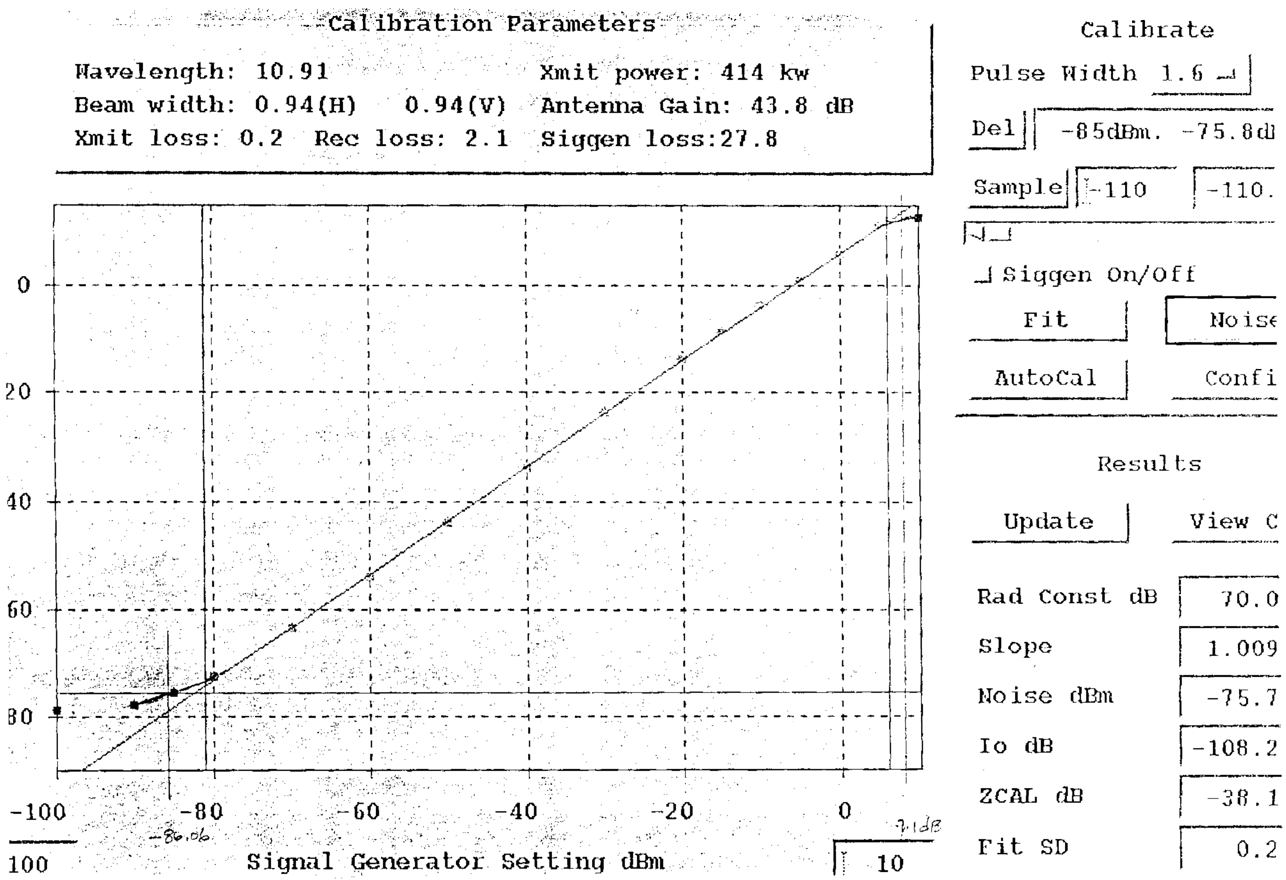


Figure 11 b Sigmet 14 bit receiver dynamic range test. Dynamic range from noise level to 1 db compression point is 93.2 dB.

5. Summary and Recommendations

The noise properties of the 12 bit receiver with a noise floor of about -63 dBc is comparable to the legacy with noise floor of about -64 dBc. However, its dynamic range of 85 dB is very marginal for the WSR-88D application with routine dynamic range of 92 dB without use of an external gain control or sensitivity time control. Neither AGC nor STC is viewed as an attractive option since the required dynamic range can be achieved with the 14 bit unit.

The 14 bit receiver has noise properties superior to the legacy receiver (although not realized in this application) and delivers the same system noise as the legacy receiver (-64 dBc). In addition, the unit has a dynamic range of 93 dB which meets or exceeds that routinely achieved with the legacy receiver. The 14 bit unit can meet or exceed the legacy receiver performance.

Considering the numerous advantages of the digital receiver over the legacy receiver, including decreased receiver parts count, simplicity of calibration, improved stability, and ease of maintenance, it is recommended that a 14 bit or a larger digital receiver be incorporated into the Open RDA before initial deployment.

Acknowledgments

The authors are indebted to NSSL for access to the radar and assisting in terminal installation, to Rick Rhoton and Rich Ice for assistance in installation, operation, and maintenance of the terminal, toValery Melnikov for the spectral density analysis and to Agnes Regier for manuscript preparation.

Appendix

Engineering description of Tests

Two types of testing were performed using RDASOT for attenuator and amplitude control as follows:

* CW Tests shown in Figure 12. The normal calibrating signals were disconnected at 4J16 and a Test Signal Generator was connected to 4J16 using a test cable. This configuration was used to measure dynamic range and a “confidence test” of phase noise. The latter, of course, did not include transmitter phase jitter, a major contributor to total phase noise.

* Klystron Output sample tests shown in Figure 13. This set up uses a sample of the Klystron output as a test signal source. Phase noise measurements using this set up *did* include the transmitter phase jitter.

CW Testing Block Diagram

Refer to Figure 12. The Test Signal is inserted into the front end of the receiver channel at 4J16. The cable from the Equipment Shelter to the Pedestal has a path loss designated by R69. This is a measured value recorded in software in the Receiver Adaptation data file. The pertinent values of path loss are shown in Table 13.

The pertinent specifications of the circuit elements shown are as follows:

* 2A1A3FL1 EMI Filter. The EMI filter is designed to eliminate interference from radiators in the S-band, such as nearby WSR-88D radars, etc. Large interference during the listening period had previously over driven the Low Noise Amplifier. The pertinent specs are as follows:
    - 0.5dB BW = 700Khz minimum
    - +/-25 Mhz from Fo 30dB minimum rejection
    - +/- 100 Mhz from Fo 60dB minimum rejection
    - Insertion loss 0.5dB maximum
    - Power handling capability up to +18dBM CW at the input to the filter

* 2A3 Receiver/Protector. This unit is designed to attenuate the high power input while the transmitter is actually transmitting the radar pulses, then switch to a low loss condition while the antenna is receiving the low power reflected radar signals. Pertinent specs are:
    - Input pulse width 4.65 usec max
    - 80dBM input peak power during transmission
    - 27dB minimum attenuation by high power diode switch section during transmission
    - +53dBM max peak input into Passive diode limiting section
    - 38dB attenuation minimum from +3dBM to +53dBM during transmission
    - 65 dB minimum attenuation total during transmission.
    - Maximum attenuation during listening period is 1.0 dB at 0 dBM input and

1.2dB at +3dBM input

*2A4 Low Noise Amplifier. This unit features very low Noise Figure, very stable gain. Pertinent specs are:

- 1.30 dB max Noise Figure
- Gain of 28+/- 0.5dB
- Gain flatness over frequency range of +/- 0.2dB
- Operating power input is -15dBM maximum
- Max peak power input of 23bDM for 4 usec. pulse duration
- 0.3dBM output compression at +12dBM minimum output
- 1.0dBM output compression at +15dBM minimum output

* 4A4 Preselect Filter. Previous to the addition of the EMI filter 2A1A3FL1, this filter was the only preselect filter in the receiver chain. Pertinent specs are:

- Operating power input is +23dBM max peak
- 0.2dB Bandwidth is 6Mhz minimum
- 3.0dB Bandwidth is 18.5 Mhz minimum to 24 Mhz maximum
- 40dB Bandwidth is 70Mhz maximum
- 60dB Bandwidth is 120Mhz maximum

* 4A5 Mixer/Preamp. This unit uses a STALO input to mix with the RF input to produce the sum and difference frequencies. The difference frequency, ie, the IF frequency is passed by an internal bandpass filter and made available at J4.

- Gain (J1 to J4) is +4.20+/- 0.75 dB
- Bandwidth (0.3B) +/- 2.5 Mhz centered at Fc
- Bandwidth (3dB) 23 to 27Mhz.
- Bandwidth (20dB) is 25Mhz minimum to 92Mhz maximum

* 4A1 Frequency Generator This unit provides the basic outputs which are required for operation of the WSR-88D radar system. The pertinent specs are as follows:

- RF   Freq =2.70 to 3.00 Ghz, accuracy = .0005% at 25deg C, stability .0005% over temp range, power output +11.75dBM to +14.25dBM, harmonic output (2nd) =- 50dBC min, all others = -60dBC min, non-harmonic output= -70dBC min
- STALO Freq = 2.6424 to 2.9424Ghz.(less than RE by 57.5491 Mhz.), power output = +14.85 to +17.0dBM, cross channel isolation from RF = 80dB min, harmonic output (2^{nd}) = -60dBC min, all others =- 70dBC min.
- COHO Freq = 57.5491 Mhz, accuracy =.0005%, power output = +26 to +28dBM, harmonic output(2nd) = -60dBC min, all others =-70dBC min

* 3dB Attenuator

- Attenuator is 3 +/- 0.2dB

* 15 dB Amplifier
  - Gain is 15dB +/- 1dB

Table 3 Path Losses

Adaptation Data	Value (dB)	Description
R69	- 4.44	Cable W53 loss
R72	- 21.30	2A1A3FL1 20dB Attenuator
R73	- 1.62	2A3 Listening loss
R74	+ 27.53	2A4 Low Noise Amp Gain
R77	- 3.80	Cable W54 loss
R81	- 2.00	4A4 Preselect Filter loss
R84	+ 3.51	4A5 Mixer/preamp gain
3dB Attenuator	- 3.00	Required by SIGMET
15dB Amplifier	+ 14.00	Required by SIGMET
PL 4J16_SIGMET IF Input	+ 8.88	Total path loss/gain

Delayed Klystron Sample Testing

Figure 13 depicts the generation of the Klystron Output Sample which was used to measure total phase noise during our recent testing. RDASOT was used to control signal amplitude and other transmitter parameters. Table 4 provides a listing of path losses from the Klystron output to 4J16. The following lists the pertinent specs for the circuit elements shown:

* 3V1 Klystron. The Klystron provides phase and amplitude stable amplification of the RF Drive applied to it. It's pertinent specs are:
  - Power output is set to 700Kw Peak (88dBM peak). The inherent amplitude stability is +/- 0.5dB. The amplitude is continuously monitored by two power monitors and corrections to the transmitted power is made in software to an accuracy of +/- 0.2dB.
  - The phase stability of the Klystron output is a function of the amplitude stability of the Modulator output of the Pulse Forming Network (PFN) which turns on the Klystron. The PFN amplitude is regulated by the Post Charge Regulator with a cycle to cycle stability of 0.01% (100PPM). This is sufficiently stable to assure a phase noise of -60dBc max.

* Arc Detector. Provides an alarm signal if visual illumination is detected at the Klystron

output as a result of an arc. Its path loss is typically -0.05dB.

* 1WG2 Harmonic Filter. This unit provides rejection of harmonics of the fundamental (2000 to 3000 Mhz) It’s pertinent characteristics are s follows:

    - Path loss -0.15dB max
    - Harmonic suppression 2^{nd} = -40 dB min, 3^{rd} = -30dB Min, 4^{th}= -20dB min
    - Power rating 1.5Mw peak, 2.5Kw average

* 1WG4 Circular

    - Path loss = -0.3dB max
    - Power rating 1.2 Mw peak, 2.5Kw average

* 1WG6 Spectrum Filter (Optional) This unit is designed to provide extra rejection of transmitted spectrum in the -40 to -80dB region. It is intended for densely populated area.

* 4A20 Coax cable

    - 1 dB path loss typical

* 4AT33 6dB attenuator

    - -6dB path loss typical

* 4A20 4 way power splitter

    - -6dB path loss typ

* 4AT34 10dB attenuator

    - -10dB path loss typ

* 4A21` 10 usec delay line. This unit provides delay of the Klystron sample so that the sample may be sampled in the receiver channel.

    - delay = 10usec typ
    - Path loss = -50dB typ

* 4A22 Four position switch. This computer-controlled switch selects four possible test inputs to the receiver channel.

    - Path loss = +9dB typ in Klystron output position

* 4A23 RF Test Attenuator. This unit provides computer selected attenuation in 1dB steps up to 103dB attenuation

    - Path loss (0dB attenuation selected) = 6.5dB typical

* 4A24 Two position switch. This unit provides computer controlled selection of the injection point of the selected test signal, either injection into the Receiver/Protector (antenna injection) or the signal coupler 4DC2 at the input to the Receiver Cabinet

    - Path loss -2.5dB typ

Table 4 Path losses from Klystron to 4J16

Adaptation data parameter	Value (dB)	Description
TR17	- 0.05	Arc Detector
TR18	- 0.15	Harmonic Filter
TR19	- 0.15	Circulator
TR20	- 0.20	Spectrum Filter
TR21	- 0.05	Path loss correction term
TR23	- 35.17	Cross guide coupler
R48	- 0.87	Coax cable
R49	- 6.00	6dB Atten
R50	- 6.29	4 way splitter
R53	- 10.15	10dB Atten
R55	- 44.84	10 usec delay line
R57	- 2.06	4 Pos switch
R63	- 5.47	RF Test Atten (0dB)
ATTEN	Variable	Selected atten step
R66	- 1.79	2 Pos switch
Total (0dB selected)	- 106.95	

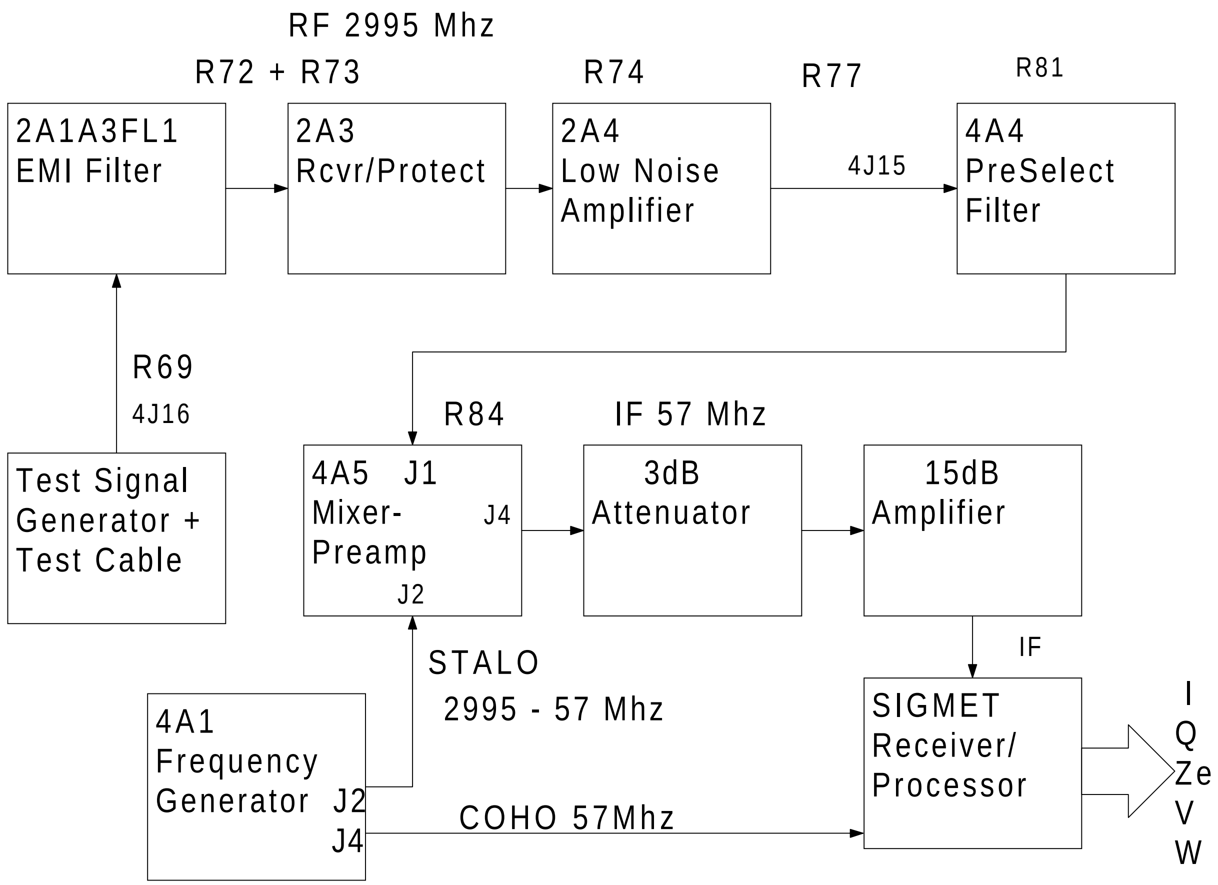


Figure 12 CW Testing Block Diagram

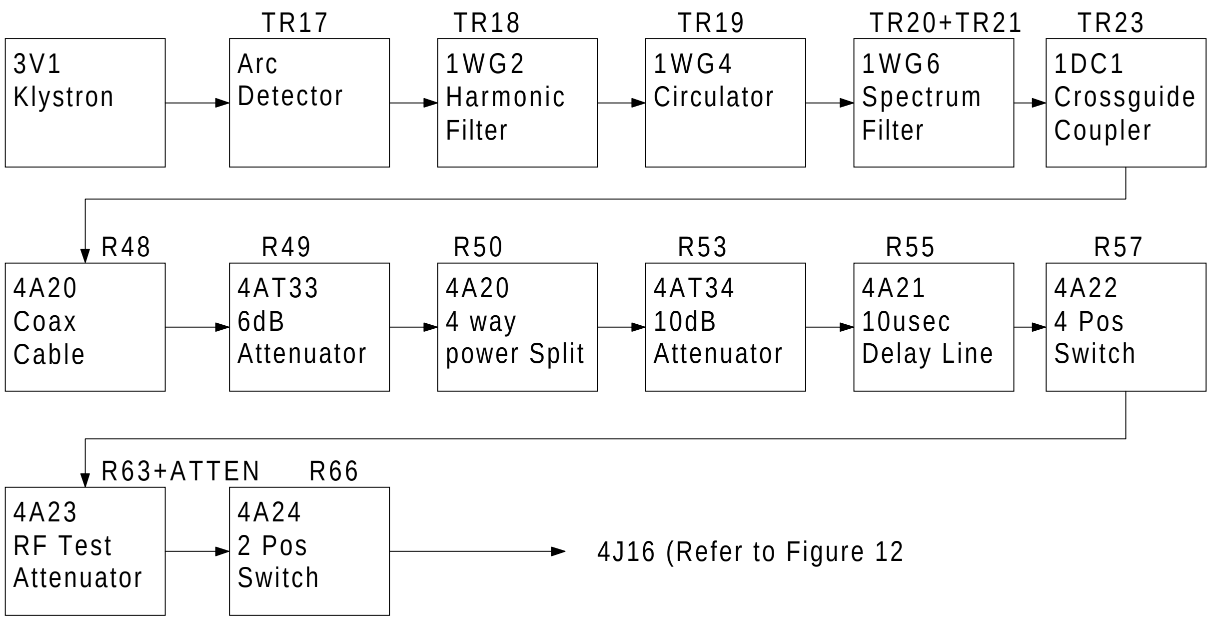


Figure 13 Klystron Sample Testing Block Diagram